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STRESS CORROSION OF HIGH-STRENGTH ALUMINUM ALLOYS

By
T. S. Humphries

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STRESS CORROSION OF HIGH-STRENGTH ALUMINUM ALLOYS

By T. S. Humphries

ABSTRACT

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The stress corrosion properties of some of the most commonly used high-strength aluminum alloys - 2014, 2024, 2219, 7075, 7178, and 7079 - are presented. The effectiveness of a few protective finishes in combating stress corrosion is also presented. Alternate immersion in 3-1/2 percent salt solution and exposure to the atmosphere at MSFC constituted the test media. It was found that all of the high-strength aluminum alloys tested were highly susceptible to stress corrosion cracking in the short transverse direction except 7075-T73 and 2219-T87. Neither chemical conversion nor anodic coatings were effective in combating stress corrosion; however, either of these coatings plus zinc chromate primer afforded considerable protection.

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STRESS CORROSION OF HIGH-STRENGTH ALUMINUM ALLOYS

by

T. S. Humphries

ENGINEERING MATERIALS BRANCH
PROPULSION AND VEHICLE ENGINEERING DIVISION

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STRESS CORROSION OF HIGH-STRENGTH ALUMINUM ALLOYS

By T. S. Humphries

SUMMARY

The high-strength aluminum alloys used for space launch vehicles possess a low order of resistance to corrosion as compared to the lower strength aluminum alloys developed for other characteristics. Because of the low safety factors used for space launch vehicle design, a program was initiated to investigate the stress corrosion characteristics of the more common high-strength aluminum alloys encountered on these vehicles. Specimens of the various alloys were stressed in the short transverse, the long transverse, and the longitudinal directions relative to the grain structure. The protective finishes currently used for aluminum components on the Saturn I Vehicle were evaluated to determine their effectiveness in combating stress corrosion. Alternate immersion in 3-1/2 percent salt solution was employed as an accelerated test medium, and specimens were also exposed to the atmosphere at MSFC.

The results indicate that the high-strength aluminum alloys - 2014, 2024, 7075, 7178, and 7079 - in the normal tempers (-T4 and -T6) are susceptible to stress corrosion cracking when stressed in the short transverse direction, and to a considerably lesser degree in the long transverse and longitudinal directions. Overaged (-T73) 7075 aluminum alloy showed a marked improvement in resistance to stress corrosion cracking over 7075-T6. Alloy 2219-T87 also exhibited a high resistance to stress corrosion cracking compared to most high-strength aluminum alloys. Neither chemical conversion nor anodic coatings were effective in combating stress corrosion of aluminum. However, either of these treatments followed by zinc chromate primer (MIL-P-8585A) afforded considerable protection against stress corrosion.

INTRODUCTION

Stress corrosion is a complex interaction of corrosive attack and sustained tensile stress at the metal surface which results in cracking or failure. Only a continuous surface tensile stress causes stress corrosion cracking, whereas intermittent stresses such as those resulting from service loadings do not. The main source of sustained tensile stress is, generally, residual stress resulting from quenching thick sections after thermal heat treatment and from certain forming operations. Other sources are constant stress applied as in interference fits, stresses produced in bolts and other threaded joints and clamps, and locked-in stress from misfits during assembly. Residual tensile stresses introduced by quenching after solution heat treatment are usually internal, with compressive stresses occurring on the surface of the material. Extensive machining may result in the exposure of tensile stresses on the surface which renders the material subject to stress corrosion. Stress corrosion cracking of susceptible aluminum alloys can occur in very mild environments, such as the atmosphere or condensed water vapor. The presence of chlorides in either of these environments will aggravate the attack.

EXPERIMENTAL PROCEDURE

Two types of specimens were employed in this work: round tensile specimens (0.125 in. diameter with 1/2 in. gage length) stressed in direct tension and "C"-rings (1.5 in. diameter with 0.064 in. wall thickness), utilizing the constant deflection method (FIG 1). Detailed descriptions of these two types of specimens are described in reference 1. These two types were chosen so that tests ~~could be~~ were conducted in all three directions - short transverse, long transverse, and longitudinal - relative to grain structure. The aluminum alloys evaluated consisted of 2214-T651, 2024-T4 and -T6, 2219-T81 and -T87, 7075-T6 and -T73, 7178-T651, 7079-T6, and 5456-H321. Alloys 2014-T651 and 7079-T6, both of which are ~~known~~ to be susceptible to stress corrosion cracking, were chosen for the evaluation of protective coatings. The protective coatings evaluated to combat stress corrosion consisted of chromic acid anodized film (MIL-A-8625A, Type I), sulfuric acid anodized film, with both hot water and dichromate seal (MIL-A-8625A, Type II), "hard" anodized film, chemical conversion coatings (~~Alodine No.~~ 1200 and Iridite No. 14-2), and one of these finishes plus two spray coats of zinc chromate primer (MIL-P-8585A).

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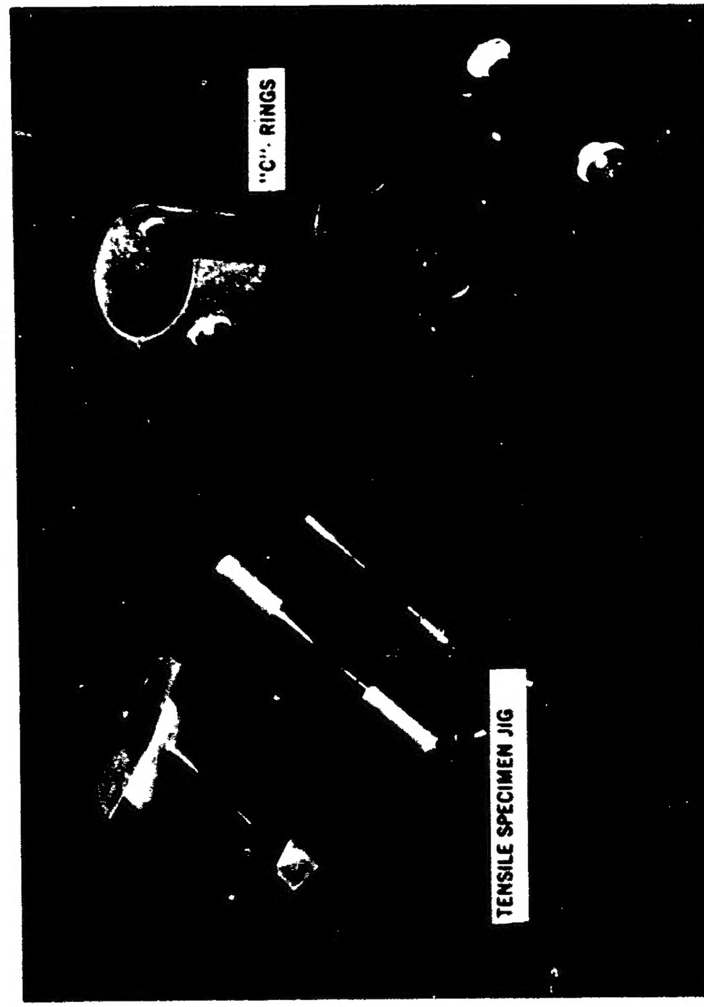

FIGURE 1 STRESS - CORROSION TEST SPECIMENS

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The test specimens were degreased with acetone, stressed to the desired level, and placed in the corrosive environments until failure occurred or until the tests were terminated. Mechanical properties of all alloys were measured in all directions of testing. Duplicate, unstressed, tensile specimens were exposed under identical conditions for control. The chosen stress level was 75 percent of the yield strength, except alloy 7079-T6 was stressed to 25, 50, 75, and 90 percent of the yield strength. Most of the results were obtained using an alternate immersion tester (FIG 2) containing a 3-1/2 percent sodium chloride solution as the test medium. This test employs a one hour cycle with ten minutes of immersion followed by fifty minutes of drying. Specimens, inclined at a 30° angle facing south, were also exposed to the atmosphere at MSFC. al

The time in days to fracture of the stressed specimens was recorded. At the time of fracture of the round tensile specimens, the duplicate unstressed specimen was removed and the mechanical properties determined to evaluate the change in properties resulting from corrosion per se. When the tests were terminated, the stressed specimens that had not failed and their corresponding unstressed specimens were removed from the alternate immersion tester and their mechanical properties measured. The comparison of these properties and the original properties gave an indication of the acceleration of corrosion resulting from stress. Although the "C"-ring type of specimen was stressed quantitatively, it could not be tested after exposure and was, therefore, a "crack-no-crack" type of test.

RESULTS AND DISCUSSION

The high-strength wrought aluminum alloys used in this investigation are divided into two general classes: the Al-Cu-Mg-Mn (2000 series) and the Al-Zn-Mg-Cu (7000 series) alloys. Although the alloys in these classes are similar in behavior, individual alloys and tempers have certain specific characteristics. As stated in reference 2, alloys 7178-T6 and 7075-T6 provide the highest strengths for thin and medium sections, while 7079-T6 alloy affords the best combination of high strength and elongation for aluminum alloys in thick sections. Alloy 2219 affords maximum tensile properties at elevated temperature in addition to good weldability, high strength, and resistance to stress corrosion. The -T73 temper was developed for alloy 7075 to provide a high resistance to stress corrosion cracking in the short transverse direction.

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FIGURE 2 ALTERNATE IMMERSION TESTER

It is generally agreed that aluminum alloys can be stressed to relatively high levels in the longitudinal and long transverse directions with very little danger of stress corrosion cracking; whereas, stress corrosion cracking will occur in the short transverse direction at a much lower level of stress. In other words, aluminum alloys exhibit the highest resistance to stress corrosion cracking in the longitudinal direction and the lowest in the short transverse direction. It is, therefore, important when conducting a comprehensive evaluation of stress corrosion cracking of aluminum to test the material in all three directions relative to grain structure. Tests in the short transverse were employed most frequently in this investigation because of the susceptibility to stress corrosion cracking in this direction. Plate, at least 2 inches thick, was necessary in order to obtain ~~round~~ tensile specimens from the short transverse direction.

The nominal composition and the mechanical properties of the alloys tested are listed in Table I. In Table II are listed the stress corrosion results employing tensile specimens alternately immersed in a 3-1/2 percent sodium chloride solution. All tests were made on 1/8 inch diameter threaded-end tensile specimens stressed to 75 percent of yield strength, unless otherwise stated in the table. It may be seen that the stress corrosion characteristics of alloys 2014-T651, 2024-T4 and -T6, 7075-T6, and 7079-T6 are similar, whereas 7178-T651 is somewhat more susceptible. The results obtained on 2024-T4 and 2024-T6 do not agree with published data by Alcoa (reference 2), which indicate that the resistance to stress corrosion cracking of 2024-T6 is superior to that of 2024-T4. It should be pointed out that the 2024-T6 specimens used in this investigation were not taken directly from 2024-T6 plate, but were obtained by artificial aging 2024-T4 specimens to the -T6 condition. Alloy 7075 in the overaged condition (7075-T73) and alloy 2219-T87 exhibited relatively high resistance to stress corrosion cracking and were comparable in performance to the intermediate-strength alloy 5456-H321, particularly in the short transverse direction. As expected, all of the alloys exhibited the lowest resistance to stress corrosion in the short transverse direction and the highest in the longitudinal direction.

Table III gives the results of the stressed specimens exposed to the atmosphere for approximately five months at MSFC. This length of exposure to a mild atmosphere is not of sufficient duration to obtain conclusive results, but the data were included for comparison with the accelerated tests. All tests were made on 1/8 inch threaded-end tensile specimens stressed to 75 percent of yield strength, except as noted in the table. Only five specimens have failed after five months of exposure to the atmosphere, and all of them were stressed in the short transverse direction. Three specimens of alloys 7079-T6 failed, and one each of alloys 2014-T651 and 2024-T4 failed, which indicates that →10

Table I. Nominal Composition and Typical Mechanical Properties of High-Strength Aluminum Alloys

Alloy	Cu	Mg	Zn	Mn	Cr	Si	Type of Temper	Tensile Strength, KSI	Yield Strength (0.2%), KSI	Elongation in 2 In. Percent
	Nominal Composition, Percent									
2014	4.4	0.4	--	0.8	--	0.8	T6(1)	62.0	42.0	20
2024	4.5	1.5	--	0.6	--	--	T4	68.0	47.0	20
							T6	69.0	57.0	10
2219	6.3	--	--	0.3	--	--	T81	65.0	52.0	11
(Also	0.1 V	and	0.15 Zr)				T87	68.0	57.0	10
7075	1.6	2.5	5.6	--	0.3	--	T6	83.0	73.0	11
							T73	73.0	63.0	13
7178	2.0	2.7	6.8	--	0.3	--	T6(1)	88.0	78.0	10
7079	0.6	3.3	4.3	0.2	0.2	--	T6	78.0	68.0	14
5456	--	5.3	--	0.8	0.1	--	H321	51.0	37.0	16

Notes: (1) The mechanical properties of tempers T6 and T651 are similar.

Table 2.

Stress Corrosion of High Strength Aluminum Alloys
Alternately Immersion in 3.5 percent salt solution

Table III. Stress Corrosion of High-Strength Aluminum Alloys in A Mild Industrial Atmosphere

Alloy and Stress Direction	Calc. Stress Level (KSI)	Tensile Strength (KSI) Original	Tensile Strength (KSI) Unstressed	Days to Failure
2014-T651				
Short Trans.	43.5	66.8	64.2	134
	43.5	66.8	----	(a)
Long Trans.	45.8	69.7	----	(a)
	45.8	69.7	----	(a)
Longitudinal	48.8	70.8	----	(a)
	48.8	70.8	----	(a)
2024-T4				
Short Trans.	36.8	63.4	58.1	[illegible]
	36.8	63.4	----	(a)
Long Trans.	35.2	65.0	----	(a)
	35.2	65.0	----	(a)
Longitudinal	36.7	63.7	----	(a)
	36.7	63.7	----	(a)
2024-T6				
Short Trans.	42.0	66.2	----	(a)
	42.0	66.2	----	(a)
Long Trans.	41.2	66.5	----	(a)
	41.2	66.5	----	(a)
Longitudinal	41.9	65.9	----	(a)
	41.9	65.7	----	(a)
2219-T81 (1 2" thick plate)				
Long Trans.	36.0	[illegible]	----	(a)
	36.0	[illegible]	----	(a)
Longitudinal	37.6	64.4	----	(a)
	37.6	64.4	----	(a)
2219-T87 (1.5" thick plate)				
Long Trans.	41.5	67.1	----	(a)
	41.5	67.1	----	(a)
Longitudinal	41.2	66.6	----	(a)
	41.2	66.6	----	(a)
[illegible]				
Short Trans.	43.1	[illegible]	----	(a)
	43.1	[illegible]	----	(a)
Long Trans.	44.0	[illegible]	----	(a)
	44.0	[illegible]	----	(a)
Longitudinal	44.5	[illegible]	----	(a)
	44.5	[illegible]	----	(a)
7075-T6				
Short Trans.	[illegible]	72.2	----	(a)
	[illegible]	72.2	----	(a)
Long Trans.	50.4	81.5	----	(a)
	50.4	81.5	----	(a)
Longitudinal	[illegible]	78.7	----	(a)
	[illegible]	78.7	----	(a)
[illegible]				
Short Trans.	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
Long Trans.	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
Longitudinal	[illegible]	71.7	----	(a)
	[illegible]	71.7	----	
[illegible] (1 4" thick plate)				
Long Trans.	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
Longitudinal	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
[illegible]-T6				
Short Trans.	[illegible] (b)	71.2	----	(a)
	[illegible] (b)	71.2	----	(a)
	[illegible] (c)	71.2	----	(a)
	[illegible] (c)	71.2	71.2	[illegible]
	[illegible]	71.2	[illegible]	[illegible]
	[illegible]	71.2	[illegible]	[illegible]
Long Trans.	52.6	[illegible]	----	(a)
	52.6	[illegible]	----	(a)
Longitudinal	49.1	[illegible]	----	(a)
[illegible]				
Short Trans.	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
Long Trans.	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)
Longitudinal	[illegible]	[illegible]	----	(a)
	[illegible]	[illegible]	----	(a)

Notes: (a) Specimens had not failed after [illegible] the test, however, [illegible].
(b) Specimens stressed to 35 percent of yield strength.
(c) Specimens stressed to [illegible] percent of yield strength.

alloy 7079-T6 is more susceptible to stress corrosion cracking in the atmosphere than the other high-strength aluminum alloys tested. There appears to be a difference in time to failure among the three stress levels (25, 50, and 75 percent of yield strength) of the short transverse specimens of alloy 7079-T6 exposed to the atmosphere. This effect of stress level was not apparent in the alternate immersion test. More significant data from the atmospheric tests should be forthcoming.

The limited stress corrosion data on 7079-T6 alloy utilizing "C"-ring type specimens, alternately immersed in a 3-1/2 percent solution of sodium chloride, are given in Table IV. The results obtained with "C"-rings stressed in the short transverse direction agreed very favorably with those obtained from corresponding round tensile specimens (see Tables II and IV). The "C"-rings stressed in the long transverse and longitudinal directions failed prematurely in comparison to corresponding round tensile specimens. It was observed, however, that all the specimens failed in the short transverse direction (FIG 3) instead of failing at the point of maximum stress. Consequently, when "C"-ring type specimens are employed for the evaluation of stress corrosion cracking, it is important to thoroughly examine the fracture to ascertain the direction of failure relative to grain structure.

The results obtained from the investigation of protective coatings to combat stress corrosion of high-strength aluminum alloys are presented in Table V and VI. It may be seen that the chemical conversion coatings (Alodine No. 1200 and Iridite No. 14-2) and anodic coatings were not effective in combating stress corrosion. Sulfuric acid anodized film sealed in a dichromate bath offered some protection in the alternate immersion tests but was not effective in the atmospheric exposure tests. The most effective coating consisted of a chemical conversion or anodic coating plus two spray coats of zinc chromate primer (MIL-P-8585A). In actual practice, the effectiveness of a protective coating is questionable because of the difficulty of maintaining complete isolation of the metal surface from the corrosive environment. Stress corrosion cracking of a highly stressed surface may be encountered when only a very small surface area is exposed, such as that resulting from holidays or small cracks in the coating. At best, protective coatings will only extend the length of time to stress corrosion cracking of susceptible alloys. In many cases, this extension may be sufficient to warrant the use of protective coatings.

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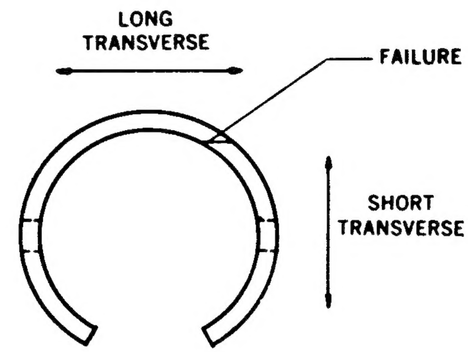

FIGURE 3 SKETCH OF "C"- RING LOADED IN LONG TRANSVERSE DIRECTION WITH FAILURE IN THE SHORT TRANSVERSE DIRECTION

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Table IV. Stress Corrosion of Aluminum Alloy 7079-T6 ("C"-Rings)

Alternately Immersed in 3.5 Percent Salt Solution

Stress Direction	Calculated Stress Level: Percent of Yield Strength	Calculated Stress Level: Stress (KSI)	Days to Failure
Short Trans.[a]	75	46.4	9
	75	46.4	12
	75	49.6	7
	75	49.6	10
	90	55.6	9
	90	55.6	14
Short Trans.[b]	75	46.4	6
	75	46.4	6
	75	46.4	3
	75	46.4	3
	90	55.6	5
	90	55.6	5
	90	55.6	2
	90	55.6	2
Long Trans.	75	49.6	43[c]
	75	49.6	47[c]
Longitudinal	75	49.6	19[c]
	75	49.6	50[c]

Notes: (a) Specimen cut from the width face. Thus, the short transverse was normal to the long transverse.

(b) Specimen cut from the length face. Thus, the short transverse was normal to the longitudinal.

(c) Specimen failed in the short transverse direction.

Table V. Stress Corrosion Protective Coatings for Aluminum (Alternately Immersed in 3.5 Percent Salt Solution)

Alloy and Protective Coating	Calc Stress Level (KSI)	Tensile Strength (KSI): Original	Tensile Strength (KSI): Final Unstressed	Days to Failure
2014-T651 Short Transverse				
Anodize Type I[a]	43.5	66.8	(d)	[illegible]
	43.5	66.8	(d)	[illegible]
Anodize Type II (hot water sealed)[a]	43.5	66.8	(d)	[illegible]
	43.5	66.8	(d)	[illegible]
Anodize Type II (dichromate sealed)[a]	43.5	66.8	(d)	[illegible]
	43.5	66.8	(d)	(e)
Anodize Type I plus 2 coats zinc chromate[c]	43.5	66.8	(d)	155
	43.5	66.8	(d)	(e)
2014-T651 Long Transverse				
Iridite[b]	45.8	64.7	(d)	[illegible]
	45.8	64.7	(d)	[illegible]
Iridite plus 2 coats zinc chromate[b]	45.8	64.7	(d)	(e)
	45.8	64.7	(d)	(e)
Iridite plus 2 coats zinc chromate[a]	45.8	64.7	(d)	(e)
	45.8	64.7	(d)	(e)
Anodize Type I[a]	45.8	64.7	(d)	155
	45.8	64.7	(d)	(e)
Anodize Type II (hot water sealed)[a]	45.8	64.7	(d)	(e)
	45.8	64.7	(d)	(e)
Anodize Type I plus 2 coats zinc chromate[c]	45.8	64.7	(d)	(e)
	45.8	64.7	(d)	(e)
2014-T651 Longitudinal				
Anodize Type I[a]	48.8	70.8	(d)	(e)
	48.8	70.8	(d)	(e)
Anodize Type I plus 2 coats zinc chromate[c]	48.8	70.8	(d)	(e)
	48.8	70.8	(d)	(e)
7079-T6 Short Transverse				
Anodize Type II (dichromate sealed)[a]	46.4	71.2	71.3	[illegible]
	46.4	71.2	----	(f)
Anodize Type II plus 2 coats zinc chromate[a]	46.4	71.2	----	(f)
	46.4	71.2	----	(f)
Hard Anodize[a]	46.4	71.2	70.1	1
	46.4	71.2	[illegible]	[illegible]
Hard Anodize plus 2 coats zinc chromate[a]	46.4	71.2	[illegible]	[illegible]
	46.4	71.2	----	[illegible]
Alodine[b]	46.4	71.2	71.2	[illegible]
	46.4	71.2	70.3	2
Alodine plus 2 coats zinc chromate[a]	46.4	71.2	72.1	135
	46.4	71.2	----	(f)

Note: (a) Surface treatment applied before stressing.

(b) Surface treatment applied after stressing.

(c) Anodized before stressing and zinc chromate primed after stressing.

(d) Surface treated, unstressed specimens were not tested.

(e) Specimen had not failed after five months of exposure.

(f) Specimens had not failed after one year of exposure.

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Table VI. Stress Corrosion Protective Coatings for Aluminum (7079-T6, Short Transverse)

Atmospheric Test

Protective Coating	Calc. Stress Level (KSI)	Tensile Properties (KSI) Original	Final Unstressed	Days to Failure
Anodize Type II (dichromate sealed)[a]	46.4 46.4	71.2 71.2	71.2 72.3	40 57
Anodize Type II plus 2 coats zinc chromate[a]	46.4 46.4	71.2 71.2	---- ----	(c) (c)
Hard Anodize[a]	46.5 46.5	71.2 71.2	72.6 73.3	6 9
Hard Anodize plus 2 coats zinc chromate[a]	46.5 46.5	71.2 71.2	---- ----	(c) (c)
Alodine[b]	46.5 46.5	71.2 71.2	71.8 ----	57 (c)
Alodine plus 2 coats zinc chromate[a]	46.5 46.5	71.2 71.2	---- ----	(c) (c)

Notes: (a) Surface treatment applied before stressing.

(b) Surface treatment applied after stressing.

(c) Specimen had not failed after five months of exposure.

CONCLUSIONS AND RECOMMENDATIONS

The results of these rather limited tests indicate that:

1. The stress corrosion characteristics of the more common high-strength aluminum alloys - 2014, 2024, 7075, 7178, and 7079 - in their normal tempers (-T4 and -T6) are similar.

2. Alloys 2219-T87 and 7075-T73 exhibited relatively high resistance to stress corrosion in the short transverse direction, and compared favorably in performance to the intermediate-strength alloy 5456-H321.

3. The aluminum alloys exhibited the least resistance to stress corrosion cracking when stressed in the short transverse direction, and the highest resistance in the longitudinal direction relative to grain structure.

4. In the accelerated test, the stress level in the range of 25 percent to 90 percent of yield strength (15 to 55 KSI) had no effect on the stress corrosion cracking susceptibility of alloy 7079-T6 in the short transverse direction.

5. Close examinations of fractures in "C"-ring type specimens used in stress corrosion tests are necessary to ascertain the direction of failure relative to the grain structure.

6. In general, chemical conversion and anodic coatings cannot be considered effective in combating stress corrosion cracking of aluminum alloys. Either of these two treatments plus two spray coats of zinc chromate primer (MIL-P-8585A) show promise in extending the time to failure of stress corrosion susceptible aluminum alloys. End

In view of the susceptibility of many aluminum alloys to stress corrosion and the variation in susceptibility caused by different heat treatments, evaluation of the newer, high-strength aluminum alloys and welded joints are planned. Stress corrosion studies will be conducted on 7001-T75, 7002-T6, 7006-T6, 7039-T6, and 2219-T31, -T37, -T62, -T81, and -T87 aluminum alloys. Welded joints of 2219 plate and forgings subjected to different heat treatments will also be evaluated. The atmospheric tests are being continued, and additional stress corrosion tests are planned for this environment. Additional investigation is needed in the field of protective coatings to combat stress corrosion cracking of susceptible alloys, and plans for such studies are being made.

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By

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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